

Quarkonia Photoproduction at Nucleus Colliders

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Abstract

Exclusive photoproduction of heavy quarkonia in high-energy ultraperipheral ion-ion interactions ($\gamma A \rightarrow V A$, where $V = J/\psi, \Upsilon$ and the nucleus A remains intact) offers a useful means to constrain the small- x nuclear gluon density. We discuss [1] preliminary results on J/ψ photoproduction in Au-Au collisions at RHIC [2], as well as full simulation-reconstruction studies of photo-produced Υ in Pb-Pb interactions at the LHC [3].

1 Introduction

The gluon density, $xG(x, Q^2)$, at small fractional momenta $x = p_{\text{parton}}/p_{\text{proton}} \lesssim 0.01$ and low, yet perturbative, Q^2 is a subject of intensive experimental and theoretical activity. On the one hand, DGLAP analyses based on DIS e -p data cannot reliably determine xG (Fig. 1) [4] as it is only indirectly constrained by the $\log(Q^2)$ dependence of the *quark* distributions (F_2 scaling violations). On the other, there are well funded theoretical arguments [5] that support the inapplicability of linear QCD (DGLAP- or BFKL-type) evolution equations at low enough values of x , due to the increasing importance of gluon-gluon fusion processes (“parton saturation”). This regime is theoretically described e.g. in the Colour-Glass-Condensate [6] or “black-disk limit” [7] approaches. Our knowledge of the low- x gluon distribution in the *nucleus* is even more scarce. Nuclear DIS data only cover the range above $x \approx 10^{-2}$ (Fig. 2), and gluon saturation effects are expected to be much larger in nuclei than in the proton due to their larger transverse parton density.

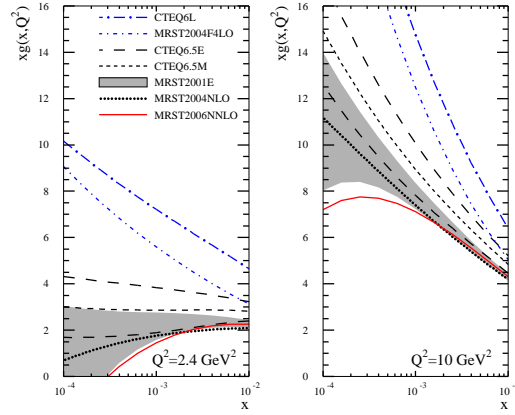


Figure 1: Comparison of recent parametrizations of the low- x gluon distribution at scales $Q^2 = 2.4$ (left) and 10 GeV^2 (right) [4].

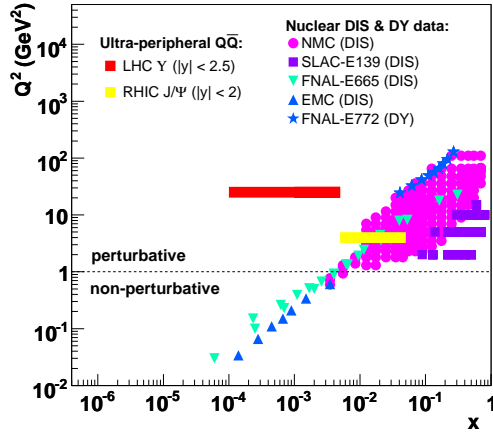


Figure 2: Kinematic (x, Q^2) plane probed in e, γ -A collisions: DIS data compared to ultraperipheral $Q\bar{Q}$ photoproduction ranges.

2 $Q\bar{Q}$ photoproduction in ultra-peripheral A-A interactions

Exclusive quarkonia photoproduction offers an attractive opportunity to constrain the low- x gluon density at moderate virtualities, since in such processes the gluon couples *directly* to the c or b quarks (see Fig. 3) and the cross section is proportional to the gluon density *squared* (see [4] and refs. therein). The mass of the $Q\bar{Q}$ vector meson introduces a relatively large scale, amenable to a perturbative QCD (pQCD) treatment.

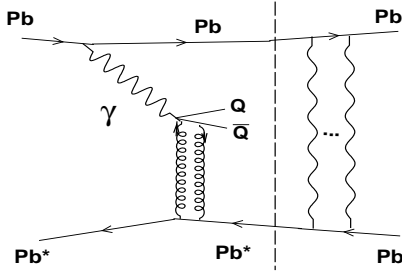


Figure 3: Schematic diagram for diffractive quarkonia photoproduction in γA collisions.

High-energy nuclear photoproduction studies are possible in Ultra-Peripheral Collisions (UPCs) of heavy-ions [8] in which the strong electromagnetic fields involved are equivalent to the exchange of quasi-real photons with maximum energies $\omega_{max} \approx 3$ GeV (100 GeV) at RHIC (LHC). Correspondingly, the maximum photon-nucleus c.m. energies are of the order $W_{\gamma A}^{max} \approx 35$ GeV (1 TeV) at RHIC (LHC). Thus, in $\gamma A \rightarrow J/\psi(\Upsilon) A^{(*)}$ processes, the gluon distribution can be probed at values as low as $x = M_V^2/W_{\gamma A}^2 \approx 10^{-2}(10^{-4})$ (Fig. 2). Gluon saturation effects are expected to reveal themselves through strong suppression of hard exclusive diffraction relative to the leading-twist approximation [7]. While this suppression may be beyond the kinematics achievable for J/ψ

photoproduction in UPCs at RHIC, $x \approx 0.01$ and $Q_{eff}^2 \approx M_V^2/4 \approx 3$ GeV², it could be important in UPCs at the LHC [8].

3 J/ψ photoproduction in Au-Au at RHIC (PHENIX)

The PHENIX experiment has measured J/ψ photoproduction at mid-rapidity in Au-Au UPCs at $\sqrt{s_{NN}} = 200$ GeV in the dielectron channel [2]. The UPC events were triggered requiring (i) a cluster in the electromagnetic calorimeter (EMCal) above 0.8 GeV, (ii) a rapidity gap in one or both $3.0 < |\eta| < 3.9$ ranges, and (iii) at least 30 GeV energy deposited in one or both of the Zero-Degree-Calorimeters (ZDCs). This last condition very efficiently selects ultra-peripheral events accompanied by forward neutron emission (Xn) coming from the electromagnetic dissociation of one (or both) Au* nuclei, which occurs with a large probability, $P_{Xn} \sim 0.64$ (at $y = 0$) at RHIC energies [9]. Electron reconstruction is done combining the central tracking devices, Ring Imaging Čerenkov (RICH) counters, and the EMCal.

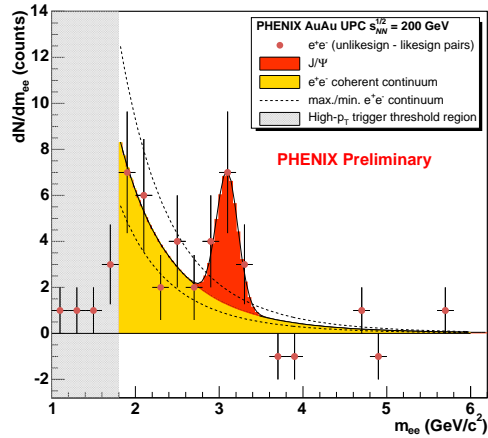


Figure 4: Invariant mass distribution of e^+e^- pairs measured in UPC Au-Au fitted to the combination of a $\gamma\gamma \rightarrow e^+e^-$ continuum plus a $\gamma A \rightarrow J/\psi A$ signal [2].

The invariant mass distribution of all reconstructed e^\pm pairs is shown in Fig. 4. The plot shows the expected $\gamma\gamma \rightarrow e^+e^-$ continuum curve combined with a fit to a Gaussian at the J/ψ peak. The total number of J/ψ 's is 10 ± 3 (stat) ± 3 (syst.), where the systematic uncertainty is dominated by the di-electron continuum subtraction. Within the (still large) experimental errors, the preliminary J/ψ cross-section of $d\sigma/dy|_{|y|<0.5} = 48 \pm 14$ (stat) ± 16 (syst) μb is consistent with various theoretical predictions [10, 11, 12, 13] (see Fig. 5, where the FGS and KST rapidity distributions have been scaled down according to [9] to account for the reduction of the yield expected when requiring coincident forward neutron emission). The band covered by the FGS predictions includes the J/ψ cross sections with and without gluon shadowing [11]. The current experimental uncertainties preclude yet any detailed conclusion regarding the nuclear gluon distribution. The possible contribution of an additional incoherent (γ -nucleon $\rightarrow J/\psi$) component – amounting to about $\sim 50\%$ of the coherent (γA) yield at $y = 0$ [11] – should be taken under consideration too.

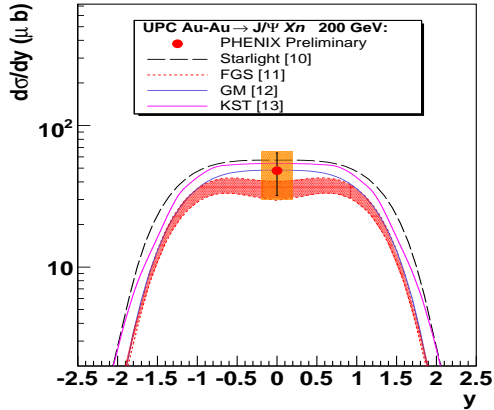


Figure 5: Preliminary cross-section of coherent J/ψ production at $y = 0$ in UPC Au-Au at $\sqrt{s_{NN}} = 200$ GeV compared to various theoretical calculations [10, 11, 12, 13].

4 Υ photoproduction in Pb-Pb at the LHC (CMS)

At the LHC energies, the cross section for $\Upsilon(1S)$ photoproduction in UPC Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV is of the order of $150 \mu\text{b}$ [10, 14]. Inclusion of leading-twist shadowing effects in the nuclear PDFs reduces the yield by up to a factor of two, $\sigma_\Upsilon = 78 \mu\text{b}$ [14]. Even larger reductions are expected in calculations including gluon-saturation (Colour Glass Condensate) effects [15].

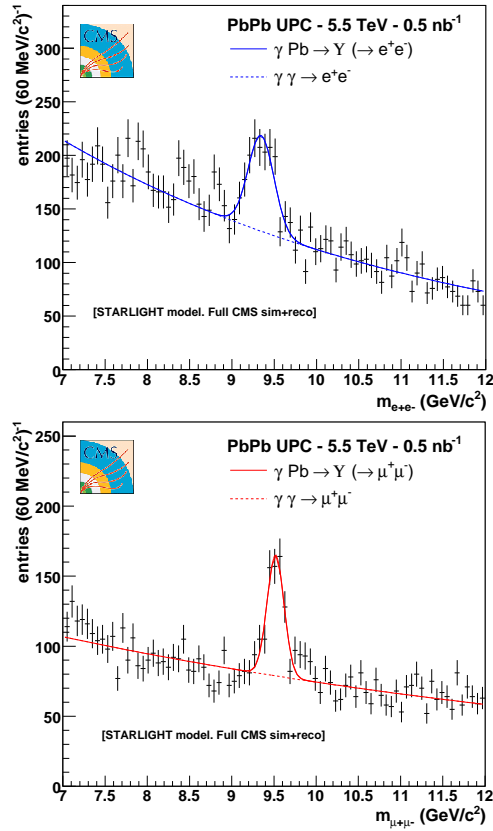


Figure 6: Expected e^+e^- (top) and $\mu^+\mu^-$ (bottom) invariant mass distributions from $\gamma\text{Pb} \rightarrow \Upsilon\text{Pb}^*$ ($\Upsilon \rightarrow l^+l^-$, signal) and $\gamma\gamma \rightarrow l^+l^-$ (background) in UPC Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV in CMS.

Full simulation+reconstruction studies [3]

of input distributions generated with the STARLIGHT MC [10] have shown that CMS can measure $\Upsilon \rightarrow e^+e^-, \mu^+\mu^-$ within $|\eta| < 2.5$, in UPCs tagged with neutrons detected in the ZDCs [16], with large efficiencies ($\epsilon_{\text{rec}} \times \text{Acc} \times \epsilon_{\text{yield-extract}} \approx 20\%$). Figure 6 shows the reconstructed dN/dm_{l+l^-} around the Υ mass (only the ground-state, $\Upsilon(1S)$, of the bottomonium family was generated). The signal over continuum background is around one for both decay modes. The total expected number of Υ events, normalised to the nominal 0.5 nb^{-1} Pb-Pb integrated luminosity, is ~ 500 , and the p_T resolution is good enough to separate the coherent (peaked at very low $p_T \approx M_V/\gamma \approx 30 \text{ MeV}/c$) from the incoherent components. With such a statistics, detailed p_T, η studies can be carried out, that will help constrain the low- x gluon density in the nucleus.

5 Summary

High-energy quarkonia photoproduction provides a particularly useful means to constrain the poorly known low- x gluon distribution of the nucleus in the clean environment of ultra-peripheral (electromagnetic) ion-ion collisions. Gluon saturation effects in the small- x domain of the nuclear wavefunction are expected to result in a suppression of hard exclusive diffraction yields relative to linear QCD expectations. We have presented preliminary PHENIX results of exclusive J/ψ photoproduction in 200-GeV Au-Au interactions, as well as the perspectives of the CMS experiment in 5.5-TeV Pb-Pb collisions at the LHC. In the absence of strong non-linear QCD effects, around 500 photo-produced Υ will be reconstructed in the CMS acceptance with nominal integrated luminosities.

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